Does an August Singularity Exist in the Northern Rockies of the United States?

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ABSTRACT

Climatic singularities offer a degree of orderliness to notable meteorological events that are typically characterized by significant temporal variability. Significant deviations from normal daily maximum temperatures that occur following the passage of a strong midlatitude cyclone in mid- to late August in the northern Rocky Mountains of the United States are recognized in the local culture as the "August Singularity." Daily standardized maximum temperature anomalies for August–October were examined for eight climate stations in Montana and Idaho as indicators of major midlatitude storms. The data indicate that a single-day negative maximum temperature singularity exists for 13 August. Further, a 3-day singularity event exists for 24–26 August. It is concluded that the concept of an August Singularity in the northern Rockies is valid, because the high frequency of recorded negative maximum temperature anomalies suggests that there are specific time intervals during late summer that are more likely to experience a major midlatitude storm. The principal benefit to society for the August Singularity is that the reduced temperatures help in the efforts to control wildfires that are common this time of year in the northern Rockies.

1. Introduction

The genesis for this research occurred on a hot summer day while working in the national forests near Missoula, Montana. While discussing the heat and poor air quality because of wildfires, a colleague from the local U.S. Forest Service office remarked that the "August Singularity" was likely in the next couple of days, because National Weather Service forecast models indicated that a midlatitude wave cyclone would bring rain and much cooler temperatures and that this would likely serve the dual purpose of improving air quality and diminishing wildfire activity (S. Shelley 2005, personal communication). Thus began a discussion about the existence of a temperature singularity for Montana weather. Although we could find no scientific publications on the topic for the northern Rocky Mountains of the United States, folklore has it that an August Singularity exists in Montana in that the first significant cold spell of the year arrives around the third week of August, typically ushered in by a major midlatitude cyclone (LaBoe 2000; Wolff 2000).

Despite the lack of documentation for Montana, singularities have long been formally recognized in meteorology (e.g., Talman 1919; Brier 1954; Newman 1965; Hayden 1976; Godfrey et al. 2002). Glickman (2000) defines a singularity as "a characteristic meteorological condition that tends to occur on or near a specific date more frequently than chance would indicate." The most analyzed singularity is the "January thaw," a multiday event in the northeastern United States that occurs around the 20–24 January (Lanzante and Harnack 1982; Guttman 1991; Godfrey et al. 2002). The depth of research on this topic is impressive, with Godfrey et al.'s (2002, p. 54) Table 1 listing 20 different studies of the January thaw with publication dates ranging from 1910 to 1991. More important, Godfre et al. (2002,

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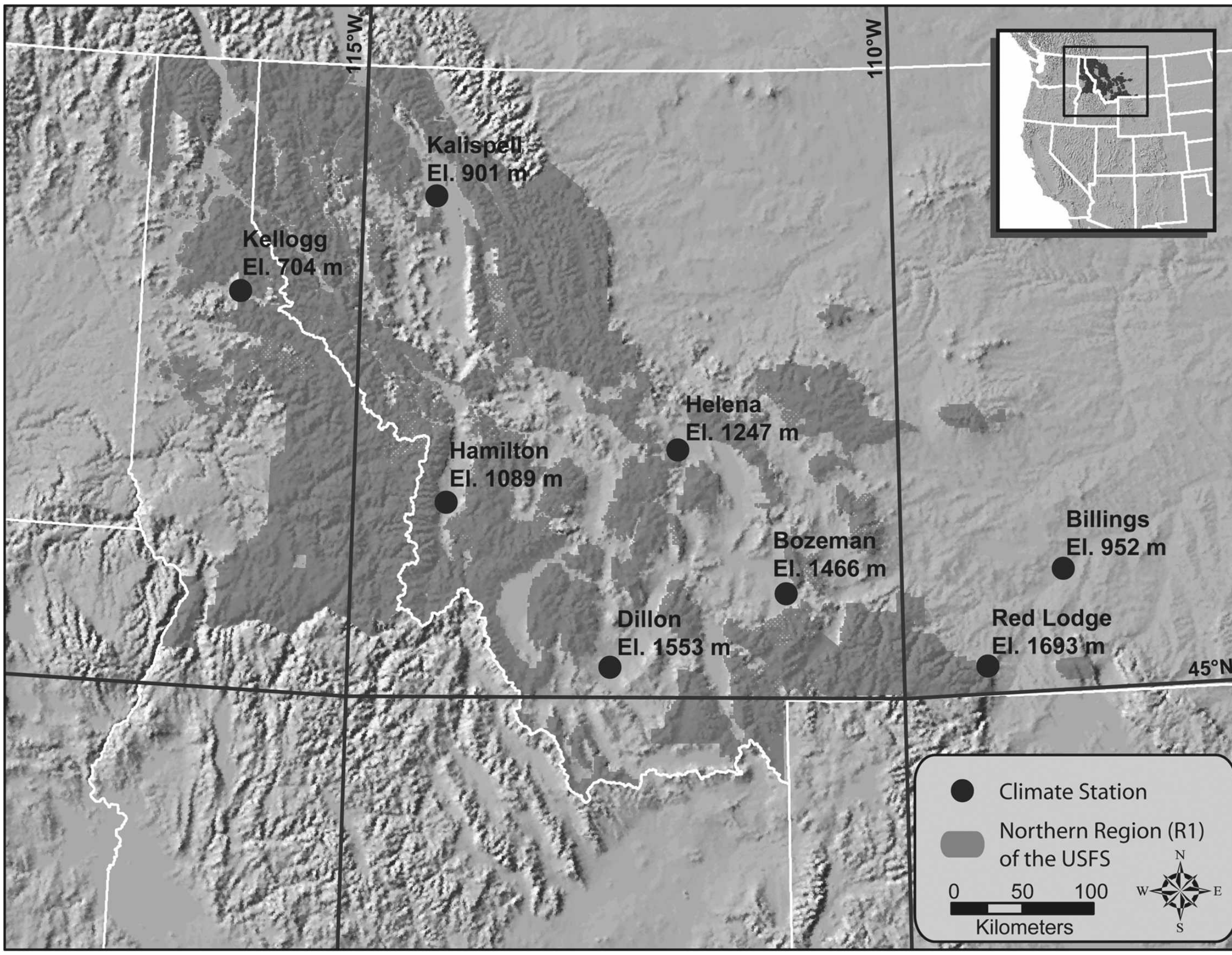

FIG. 1. Location and elevation of study sites, and boundary of the Northern Region of the U.S. Forest Service.

p. 61) note that humans seek to find "order in nature," regardless of whether a particular pattern truly exists. Thus, in the case of western Montana and northern Idaho, a region dominated by forested lands that are an integral part of the region's economy, it is understandable that emphasis is placed on the timing of such an event given the ramifications of controlling forest fires that occur each summer (Knapp and Soulé 2007). Here we determine whether a midsummer/early-autumn singularity exists in the northern U.S. Rockies as defined by negative maximum temperature anomalies (NMTAs). NMTAs are typically caused by the passage of strong midlatitude cyclones and trailing anticyclones that bring significantly colder air into the region, resulting in decreases in daytime temperatures relative to long-term climatic normals.

2. Methods

We assembled a dataset consisting of maximum daily temperatures for August, September, and October for eight sites within what the U.S. Forest Service designates as the Northern Region (hereinafter called the northern Rockies; Fig. 1) for the 1900–2004 (but 1906–2004 for Kellogg, Idaho). The selection of these three months allowed us to investigate the singularity during the critical midsummer/early-autumn fire season in the northern Rockies. We obtained all data from National Climatic Data Center *Summary of the Day* data files (NCDC 2004), and all sites had a data completeness of more than 90%. Because we did not replace any missing data in the dataset, a small number of NMTAs may have gone unrecorded at a given site. However, it was extremely unlikely that we missed recording an NMTA. Whenever an individual site had missing data, we examined the record from the remaining stations; there were no NMTAs recorded at any site on days with missing data for individual sites.

We first tested the maximum temperature data from each site for modified yeardays (1 August = yearday 1) for normality using the Shapiro–Wilk test (84 days of normality tests for the 105-yr period 1900–2004 for eight sites), a null hypothesis of no significant difference from a normal distribution, and $\alpha = 0.01$. Because the majority of days were normally distributed ($p > 0.01$) at each site, we calculated standardized Z scores [(observation i − mean)/standard deviation] (McGrew and Monroe 2000) for each observation.

Our definition of an NMTA was based on the cumulative Z-score values over 2–5 successive days. To be counted as an NMTA, the cumulative Z-score values were required to be ≤ -4.0 for 2-day events, ≤ -5 for 3-day events, ≤ -6.0 for 4-day events, and ≤ -7.0 for 5-day events. We chose a liberal definition for the starting day of an NMTA (Z score < 0) to be able to capture the transition of air masses in slow-moving synoptic systems. Beyond the first day, we required the Z score to remain < -0.5 to maintain the NMTA, because a return to values > -0.5 would likely signal a transition to a new airmass regime. Thus, if seven days in sequence had standardized scores of 0.8, −2.1, −2.3, −0.3, −1.5, −2.6, and −0.1, a 2-day NMTA would have been counted for the second and fifth days. Once the cumulative Z-score threshold was reached, any event extending beyond 5 days was maintained as long as the daily Z scores remained < -0.5. Using a definition based on multiple days allowed us to identify NMTAs that were not temporally or spatially isolated, but rather were events caused by synoptic-scale weather systems. Further, the magnitude of the cumulative deviations employed in the definition ensured that these were rare events. For example, the probability of having an individual day record a Z score of −2.0 (the average value of a 2-day, −4.0 cumulative Z-score event) is 2.28%, but the probability of having two consecutive days with a Z score of −2.0 is substantially lower (0.05%), and the probability of having three consecutive days with a Z score of −1.7 (the average value of a 3-day, −5.0 cumulative Z-score event) is lower still (0.009%).

We selected the time span from 5 August to 27 October in which to search for singularities for two reasons. First, we wanted to place the potential August event in a broader temporal context than one month. Second, to include those months in which fire behavior could be dramatically affected by a fixed-date or multiday event in the middle to latter half of the fire season, we focused on August–October. Because we did not consider daily data from July or November, NMTAs counted on 1–4 August could have been included in the tabulation of NMTAs occurring from 28–31 July and would thus have been overrepresented. In a similar way, NMTAs assigned to 28–31 October are likely undercounted because they would have been affected by 1–4 November data.

If an NMTA singularity exists, then one or more days should record more NMTAs than would be expected relative to the mean of the distribution. Although each NMTA sequence occurred over multiple days, we identified each NMTA by the modified yearday of the first day of the event. Our NMTA dataset consisted of daily counts of the total number of recorded NMTAs across the eight study sites for each of the 84 days in midsummer/early autumn. We then tested this dataset for normality using the Shapiro–Wilk test, a null hypothesis of no significant difference from a normal distribution, and $\alpha = 0.01$. Because these data were not significantly different from a normal distribution ($p = 0.305$), we were able to use the normal probability distribution to directly calculate the daily probabilities. Specifically, we took the daily (84 calendar days) total (105 yr) of NMTAs recorded across the eight study sites and standardized that measurement into a Z score. We then identified the area under the normal curve associated with a Z score of that magnitude and subtracted it from 1, yielding the probability of obtaining that large a number of NMTAs on a given day (McGrew and Monroe 2000). For example, if the total number of NMTAs recorded on a given calendar day produced a Z score of 2.0, then the probability of having that large a number of NMTAs on that day of the 84-day period would have been 0.0228 (2.28%). If the probability of any given day's total number of NMTAs was <1% ($p < 0.01$), we concluded that it was unlikely to have occurred by chance alone, thus suggesting a "single day" singularity for that calendar day.

Because of the transient nature of the synoptic systems causing NMTAs and the spatial separation among our eight study sites, an individual event typically affects the sites on different, but successive, days (e.g., Fig. 2). To account for this fact, we calculated 3-day running means of total NMTAs and assigned the 3-day mean to the middle day of the 3-day period. Whereas the single-day calculations reflect how many places experienced day 1 of an NMTA event, the 3-day calculations reflect the migratory nature of the NMTAs. We tested the dataset containing the 3-day running means of NMTAs for normality using the Shapiro–Wilk test, a null hypothesis of no significant difference from a normal distribution, and $\alpha = 0.01$ and found them to be normally distributed ($p = 0.104$; $n = 82$). We then calculated the probability of obtaining 3-day means of total NMTAs using the method employed for single days.

To determine if there were trends in total recorded NMTAs within the 84-day study period, we tested the dataset containing the daily totals of NMTAs across the

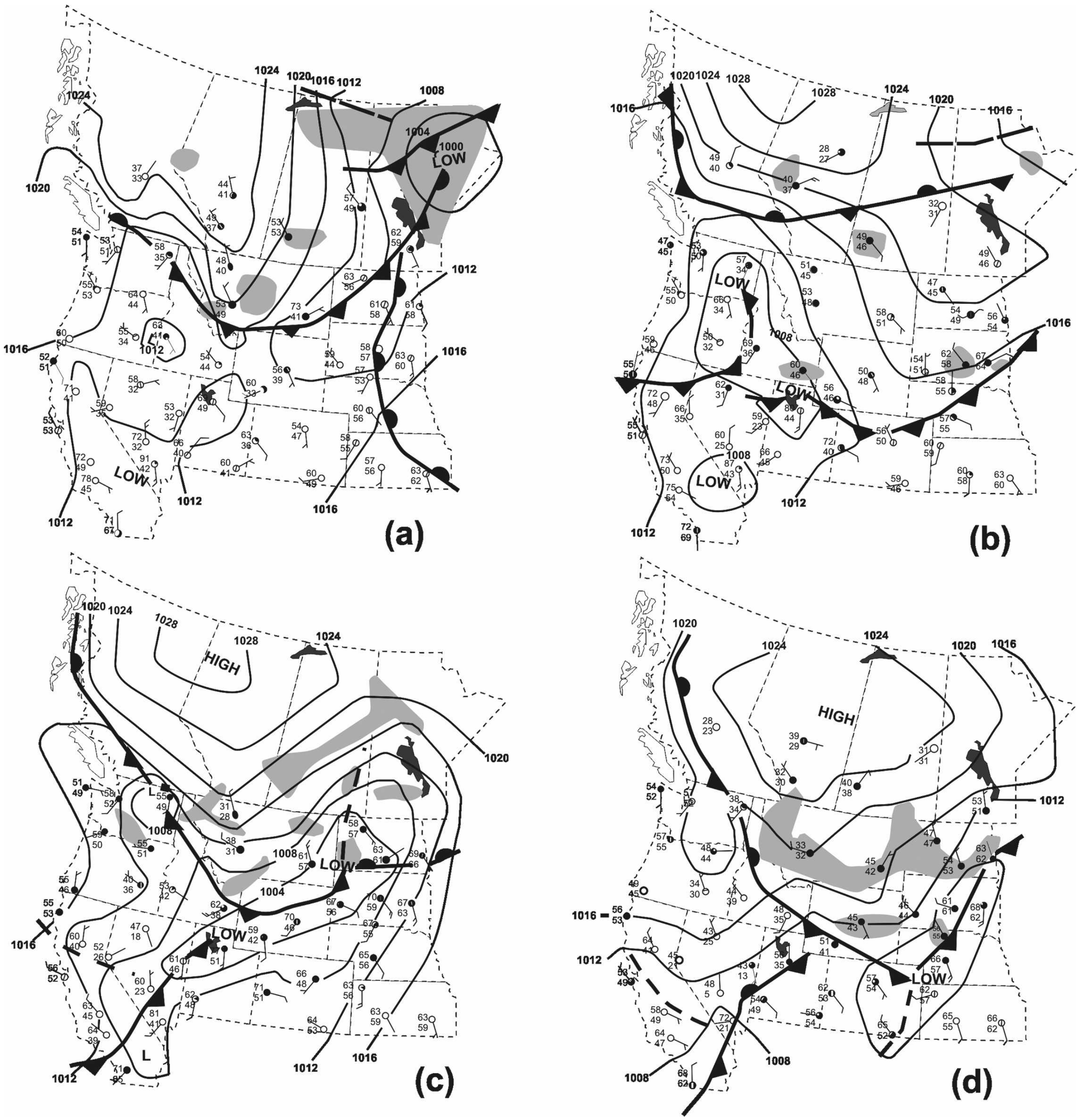

FIG. 2. Weather maps of the first four days of an August 1992 NMTA sequence. The system (a) entered Montana/northern Idaho on 20 Aug and (b) advanced southward on 21 Aug. Widespread precipitation (gray areas) occurred on (c) 22 and (d) 23 Aug (National Oceanic and Atmospheric Administration 2007).

eight sites for linearity by creating linear regression models and a suite of nonlinear regression models (e.g., logarithmic, inverse, quadratic, cubic, power, compound, *s*, logistic, growth, and exponential) with daily total NMTAs as the dependent variable and time (modified yearday) as the independent variable, and $\alpha = 0.01$. All of the models were nonsignificant.

3. Results and discussion

A 1992 NMTA event (Fig. 2) represents an example for our study period. The NMTA began on 20 August at Kalispell and Helena, on 21 August at Billings, Bozeman, and Red Lodge, on 22 August at Dillon and Hamilton, and finally at Kellogg on 23 August (all locations

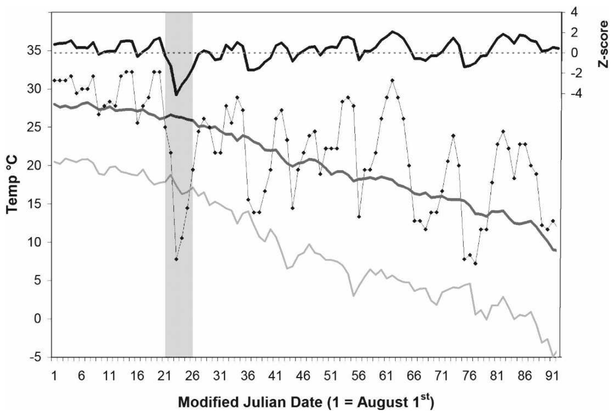

FIG. 3. The 1900–2004 mean maximum daily temperatures (dark gray line) and two (negative) standard deviations (light gray line) for Bozeman from 1 Aug through 31 Oct. The thin black line with markers depicts the daily mean temperature at Bozeman in 1992, and the thick black line is the standardized score of daily temperature at Bozeman in 1992 (right vertical axis). An NMTA beginning 21 Aug 1992 is highlighted (gray shading).

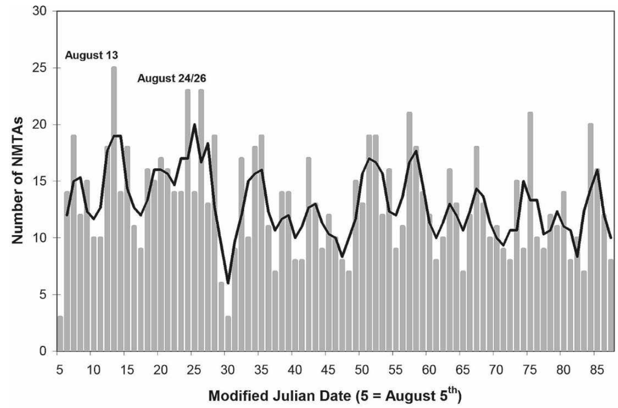

FIG. 4. Single-day totals (vertical bars) of NMTAs for all eight study sites combined, and 3-day running means (black line) of total NMTAs from 5 Aug through 27 Oct (13, 24, and 26 Aug are identified) over 1900–2004.

are in Montana except Kellogg, which is in Idaho). Northwesterly flow from a surface high pressure system centered near the Alberta/British Columbia (Canada) border followed a cold-frontal passage through the region on 20 August, bringing the initial wave of cold air. The pattern was reinforced by a second cold front and strengthening high pressure over Alberta/British Columbia between 21 and 22 August. By 23 August, the maximum temperature in Bozeman was 7.8°C, or 4.2 standard deviations below the mean for this day. This event exceeded our threshold for recording an NMTA at Bozeman: the cumulative Z score for the 4-day period shown in Fig. 2 was -9.0. The daily temperature pattern for Bozeman in 1992 clearly illustrates this event, with maximum temperatures falling below normal on 21 August and remaining well below normal for several days (Fig. 3).

The midsummer/early-autumn pattern of single-day ($n = 84$) total NMTAs across the eight study sites ranged from 3 to 25, with a mean of 13 (Fig. 4). The highest daily total of NMTAs was recorded on 13 August (25 NMTAs; Z score = 2.61), with the second greatest (23 NMTAs; Z score = 2.18) occurring on 24 and 26 August (Fig. 4). The calculated probability of receiving 25 NMTAs is <1% ($p = 0.0045$); thus we conclude that a single-day NMTA singularity exists for 13 August. For 23 NMTAs (24 and 26 August), the NMTA probability exceeds the 1% level ($p = 0.0146$). For the 3-day means of total NMTAs, the highest value occurred on 25 August, with an average of 20 NMTAs ($Z = 2.41$) recorded from 24 to 26 August. The probability of a 3-day average this large ($p = 0.008$) is less than 1%, thus indicating that a 3-day NMTA singularity exists for this time period. Although the secondary peak of 3-day NMTAs was centered on the day of the single-day NMTA (13 August) (Fig. 4), the probability of recording the 3-day average of 19 NMTAs exceeded 1% (0.0179).

Our results indicate that a single-day NMTA singularity in the northern Rockies is statistically significant for 13 August. The popular notion that "dramatic" deviations from normally high summer temperatures occur in late August in Montana (Wolff 2000, p. 2) is also statistically valid, with the midsummer/early-autumn pattern of NMTAs from over 100 yr of data peaking during the fourth week of August (Fig. 4). Changing upper-level circulation patterns would logically be the driving force behind significant surface temperature anomalies, but prior analyses of singularities that relate to our study region are contradictory. Based on an analysis of 700-hPa height deviations from calculated harmonics, Lanzante (1983, p. 972) found that the 13 and 24–26 August Singularities occur within a time frame when the 700-hPa "deviation field is very weak," suggesting that the August period would not be conducive for producing surface singularities. Kalnicky (1987, p. 1496) conversely used factor analysis to examine day to day changes of "Dzerdzeevskii's Northern Hemisphere extratropical latitude circulation types" and found that 20 August was a date on which the 700-hPa patterns tended to shift to increasing meridionality, which our findings support.

4. Summary

We conclude that a negative maximum temperature anomaly singularity (i.e., the August Singularity) exists in the northern Rockies, with the 3-day event supporting the collective meteorological memory of residents in identifying this period as being climatically anomalous. Whereas the "January thaw" in the Northeast does not exceed frequencies in "what might be expected by chance alone" (Godfrey et al. 2002, p. 61), our analyses suggest that in our dataset negative maximum temperature anomaly singularities occur for both 13 and 24–26 August. Because NMTAs typically occur during postfrontal, anticyclonic conditions, they are related to significant improvements in air quality that aid individuals with physical conditions aggravated by atmospheric pollutants. Further, as noted in the 2003 seasonal assessment outlook for the northern Rockies provided by the National Interagency Fire Center, "August Singularity storms can be expected to place a slowing effect on fire activity" (Garfin et al. 2003, p. 9). Thus, the tendency for NMTAs to occur more frequently in mid- to late August when wildfire activity is typically high is beneficial for control efforts, because the lower temperatures associated with NMTAs help to reduce the probability of fire ignition and spread (Zimmerman and Bunnell 1998).

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